Geospatial behavior of pollinators

Maurici Ruiz
Universitat de les Illes Balears
GIS and Remote Sensing Service
Palma, Spain
maurici.ruiz@uib.es

Alicia Marqués
Universitat de les Illes Balears
Laboratory of Zoology,
Department of Biology
Palma, Spain
a.marques@uib.es

M. Mar Leza
Universitat de les Illes Balears
Laboratory of Zoology
Department of Biology
Palma, Spain
mar.leza@uib.es

Abstract

The expansion of urbanized spaces and the increase of pollution is producing a progressive decrease in the number of pollinating insects. In the case of the cultivation of the almond tree in Mallorca, this reduction can bring with it the reduction of agricultural production, the degradation of the cultivated areas and the loss of the traditional landscape. Techniques for reintroducing pollinators have been initiated in several plots in Mallorca in order to ensure the maintenance of traditional almond species and increase their productivity. A spatial autocorrelation analysis of the distribution of almonds production in a plot has been carried out in relation to the pollinator's release site and various physical variables of the plot. The almond production of each tree has been monitored for three years and its relationships with different environmental variables as the topography, height and density of the vegetation have been explored. The results show a significant relation of the production to the proximity of the point of release of the insects, as well as a tendency to the increase of productivity in the areas of the plot with higher elevation with Southwest orientation. The analysis developed provides support for the management of almond crops in the Mediterranean and the maintenance of traditional landscapes. The work involves the integration of LiDAR techniques and spatial analysis in the field of precision agriculture and environmental management.

Keywords: Pollinators, almonds, autocorrelation, precision farming, *Bombus terrestris*

1 Introduction

The Balearic Islands constitute one of the main regions of almond (*Prunus dulcis*) production in Spain which, after California, is the largest producer of this crop in the world (FAO, 2010). Most of the commercial varieties of almond trees are self-incompatible, so their own pollen cannot fecund their ovules. For this reason, the intervention of a pollinator vector is necessary to produce fruits (Rallo, 1987; Socias i Company et al., 2013).

The honeybees (*Apis mellifera*) are the traditional pollinator of the almond tree, however, in recent years its number has decreased considerably due to various causes (insecticides, parasites, pathogens, etc.) (Potts et al.., 2010). Natural pollination is in a global crisis and especially at the island level (Goulson, 2015).One solution to this problem is the artificial use of new pollinators in crops.

The objective of this article is to analyse the effect of the introduction of bumblebees, *Bombus terrestris,* in an almond crop field to promote the natural pollination of trees to maintain and increase production (Ahmad, et al., 2015; Dag et al., 2006). We are interested in knowing the distribution model of the *Bombus terrestris* in relation to environmental variables of the crop. It is also desired to analyse their behaviour and mobility in the plot with respect to the initial position of the colony. The interest is to optimize the application of this pollinator in the future in various areas of the Balearic Islands to increase the production of almonds and maintain the traditional rural landscape of the islands.

2 Methods

An analysis of the agricultural production is carried out in two plots with almond cultivation located in the Southeast area of the Island of Mallorca. One of them will be used as a control, while in the other the manual introduction of pollinators will be done (Figure 1).

The study was developed during three consecutive years 2015-2016-2017. During 2015 and 2016, a total of 18 bumblebee colonies (purchased from Koppert Biological Systems (Netherlands)) were placed each year in the Bb plot. Three Bb colonies of Koppert are necessary for each hectare. We distributed the colonies in 6 pallets (3 nests of each pallet) which were placed in two rows at the centre of the plot. In 2017, the same amount of bumblebee colonies was distributed homogeneously in the plot. The production of almonds was measured by the number of fruits obtained in both plots. In the farm test, the number of fruits in different trees was sampled.

Figure 1: Location of plots in Mallorca Island

For the analysis of the spatial distribution of fruit production, the Moran Global and Local Index has been used. Moran's statistics is an indicator of global spatial autocorrelation. It's a cross-product statistic between a variable and its spatial lag with the variable expressed in deviations of its mean (Geoda, 2018).

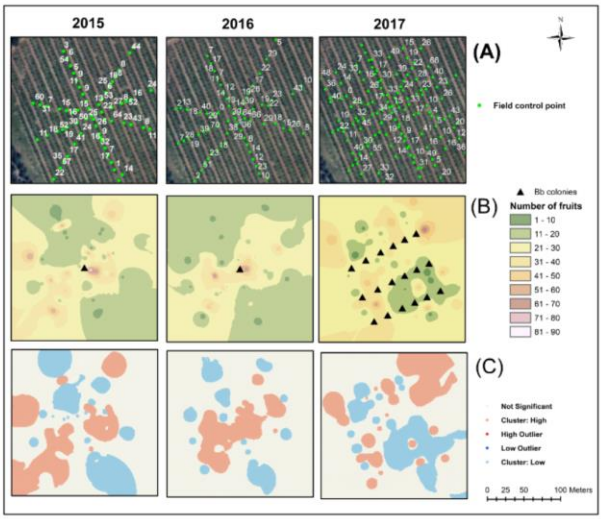
The software used for the statistical analysis and graphic representation were ArcMap ver. 10.4 and Geoda 1.12.

2.1 Fruit distribution

An interpolation inverse distance weighted (IDW) of the number of fruits for the plot is made from the information of the trees sampled (Fig. 2 a). A cell size of 1x1 m is established.

Three maps are obtained corresponding to the years of follow-up (Fig. 2 b). Next, a Moran's Global and Moran's Local spatial autocorrelation analysis is carried out in order to identify possible patterns in the production of the crop (Fig. 2c).

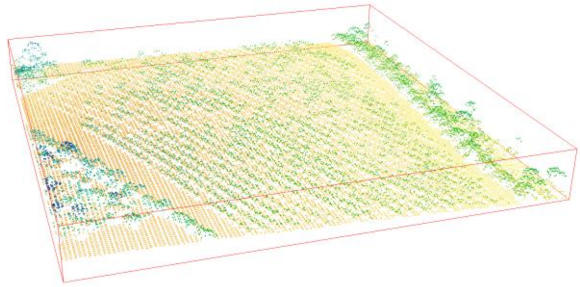
Figure 2: (a) Distribution of selected trees in Bb plot in three years of the study. (b) Distribution of fruit set in Bb plot. The black points represent the Bb colonies. (c) Hotspots of FS distribution in Bb plot.



2.2 Environmental variables

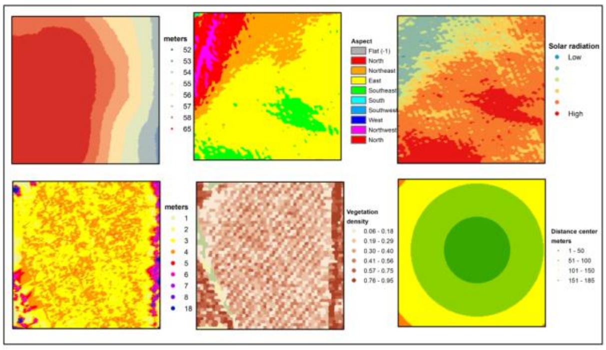
Based on the LiDAR data of the Spanish National Geographic Institute (IGN) the topography of the farm is obtained (Figure 1) and associated variables: orientation, degree of insolation, height of vegetation, density of vegetation (Figure 2). The density of points is 0.5 points/m^2 and 20 cm in elevation.

Figure 3: LiDAR view of Bb plot (resolution 2x2 m)



The topography of the plot is not very important, however, it shows a little elevation towards the Southwest. So, the topography gives rise to a preferential orientation towards the West. The height and density of the vegetation is not significant. The height of the trees is homogeneous and there are no significant variations in its height or density.

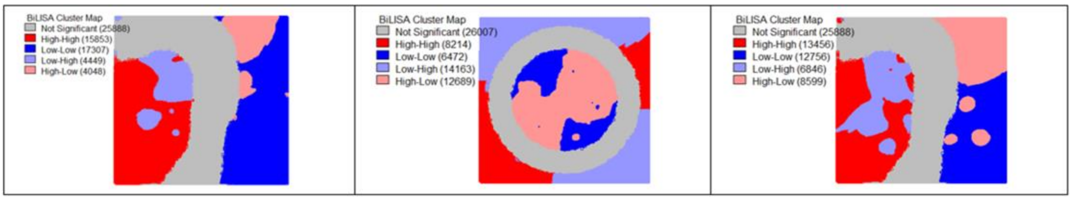
Figure 4: Main environmental variables: Orientation, solar radiation, vegetation density and distance from the colony.



2.3 Detection of patterns

First, an analysis of the global spatial autocorrelation of the fructification distribution is carried out for each of the sampling years (Table 1).

Figure 5: Local Indicators of Spatial Association (p<=0.05) a) Fruits 2015/Topography b) Fruits2016/Distance to colony c) Fruits 2017/Topography



Then, a bivariate spatial autocorrelation analysis of the fructification is carried out with respect to the proximity to the point of origin of the colony and with respect to several environmental variables of the plot (Figure 5) (Table 2).

Table 1: Moran's Global

	2015	2016	2017
Morans I	0.998	0.999	0.998
Pvalue	0	0	0
Zscore	366.185	366.706	366.360

Table 2: Bivariate Moran's Local

Bivariate Local Morans'I	2015	2016	2017
Distance to the colony	-0.082	-0.434	-0.001
Density of vegetation	-0.030	0.029	-0.037
Vegetation High	-0.028	-0.016	-0.020
Topography	0.415	0.258	0.112
Aspect	0.218	-0.063	0.044
Solar radiation	0.187	0.295	-0.107
Bombus 2015		0.545	0.273
Bombus 2016	0.545		0.097
Bombus 2017	0.273	0.097	

2.4 Prediction of fruit production

Finally, an OLS regression analysis has been carried out to establish a relationship between the productivity of the trees and the characteristics of the plot and the place of release of the colony of the pollinator.

Table 3

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SUMMARY OF OUTPUT: ORDINARY LEAST SQUARES ESTIMATION
Data set            :  Bombus_Punts_Integral
Dependent Variable  :        b2015  Number of Observations:67545
Mean dependent var  :      22.5902  Number of Variables   :     7
S.D. dependent var  :      7.21463  Degrees of Freedom    :67538

R-squared           :     0.233281  F-statistic           :    3424.85
Adjusted R-squared  :     0.233213  Prob(F-statistic)     :          0
Sum squared residual:2.69561e+006  Log likelihood        :    -220347
Sigma-square        :      39.9125  Akaike info criterion :     440709
S.E. of regression  :      6.31764  Schwarz criterion     :     440773
Sigma-square ML     :      39.9084
S.E of regression ML:      6.31731

-----------------------------------------------------------------------------
       Variable      Coefficient      Std.Error    t-Statistic   Probability
-----------------------------------------------------------------------------
          CONSTANT      -107.78        1.48409       -72.6239      0.00000
              topo     0.719395     0.00681526        105.556      0.00000
            ASPECT    0.0136369    0.000310621         43.902      0.00000
         SOLAR_RAD 8.19541e-005   1.33125e-006        61.5617      0.00000
        distcentre  -0.00585465    0.000698835       -8.37774      0.00000
            dsmVeg   -0.0174445      0.0152273       -1.14561      0.25197
           DENSITY     0.171233       0.111062        1.54178      0.12328
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3 Results

The productivity of the test plot and the control plot confirm a substantial increase in the production of almonds from the farm where the *Bombus terrestris* pollinator has been introduced.

The distribution of production for the years 2015, 2016 and 2017 (Figure 2) develops a significant spatial autocorrelation pattern (Moran's Global coefficients very close to 1 for all years) (Table 1).

Moran's Local analysis of fruit production confirms the existence of zonal autocorrelation in the plot. The tendency of expansion towards the South West zone is clearly detected for the years 2015 and 2016. The distribution of fruits of the plot for the year 2017 shows a model less correlated with the aspect (Fig. 2).

The Morans'I bivariate analysis confirms a relationship between the distribution of production for the different years and different environmental variables of the plot (Table 2). The HH values (High fruit production / High distance) seem to follow a South / West direction line.

There are few relationships between the almonds production for 2017 and the environmental variables, only seems to be maintained some trend with the topography. Figure (4c).

Finally, it is worth mentioning the high spatial correlation between fruiting in 2015 and 2016. The fruit production pattern is very similar.

The obtained result shows that there is a significant spatial autocorrelation for the distributions of the number of fruits for the years 2015, 2016, 2017. There seems to be a local spatial autocorrelation that relates the distribution of fructification with the proximity to point of release of the colony of pollinator and the topography of the plot. This relationship is more evident for the years 2015 and 2016.

The OLS regression analysis is not conclusive about the fact that fruit production can be deduced specifically from the factors considered (Adjusted R-squared 0.23). However, if the importance of topographic factors in the pollination process is evident. Geographic Weighted regression could be applied to check local dependence of the movement of the pollinator with environment variables.

The most significant relationships between variables are the following:

- Production 2015 is related with the topography and orientation of the plot. There is a tendency to group the highest fruiting values in the highest area of the plot. (Fig. 4a). The values HH (High fruit production / High elevation) are located mainly in the South West sector.
- Productivity of 2016 is related to distance to the point of release of colony of pollinator, topography and solar radiation.
- The proximity to the origin of the colony and the topography determine the distribution of the fruit production (Fig. 4b).

Bombus terrestris is an excellent almond pollinator in Mallorca. In the coming years, it is expected that its use will be much more intense on the part of the farmers. It has been possible to analyse that its spatial behaviour has a direct effect on crop production. Since its use can be expensive, it is important to know how to optimize its location on farms. For this reason, it is important to know what kind of environmental factors may increase their mobility and increase the effectiveness of their use.

5 Conclusion

The knowledge of the behaviour of pollinators in a crop in relation to the environmental characteristics of the plot and the location of the point of release of the pollinator colonies can help optimize their use. Small environmental variations in terms of topography, orientation or insolation of the plots can produce significant changes in production. The knowledge of the movement dynamics of pollinators can favour the maintenance of traditional crops in danger of disappearing.

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